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Response Selection Modulates Visual Search Within and Across Dimensions

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In feature search tasks, uncertainty about the dimension on which targets differ from the nontargets hampers search performance relative to a situation in which this dimension is known in advance. Typically, these cross-dimensional costs are associated with less efficient guidance of attention to the target. In the present study, participants either had to perform a feature search task or had to perform a nonsearch task, that is, respond to a target presented without nontargets. The target varied either in one dimension or across dimensions. The results showed similar effects both in search and nonsearch conditions: Preknowledge of the target dimension gave shorter response times than when the dimension was unknown. Similar results were found using a trial-by-trial cueing. It is concluded that effects that typically have been attributed to early top-down modulation of attentional guidance may represent effects that occur later in processing.

How do we select information from the environment? This has been a topic of research for the last 20 years. Typically, the paradigm of visual search is one of the most widely used methods to study the way we select information from the environment. In this paradigm, participants have to detect one defined target that is presented among a variable number of nontarget elements. In most versions of this paradigm, the target either differs from nontargets in one dimension (i.e., a feature search task) or differs in two (or more) dimensions (i.e., a conjunction search task). Typically, participants detect the presence or absence of the target. Time to detect the target is plotted as a function of the number of items in the display (set size). For the simple feature searches, detection of the target is independent of the number of nontargets, as shown by a flat function relating set size to reaction times (RTs). This result is taken as evidence for a parallel, efficient search process in order to detect the target. Feature search is sometimes referred to as *singleton search* or *pop-out target detection*. In a conjunction search, however, the corresponding function is linearly increasing. This pattern has been taken as evidence for a serial, inefficient search process (Treisman & Gelade, 1980).

Typically, in feature search, both the target dimension (e.g., color) and the target feature value in this dimension (e.g., red) are constant and known to the participant. For example, participants consistently search for red among green items. Recently, there has been a renewed interest in feature search (e.g., Cohen & Magen, 1999; Müller, Heller, & Ziegler, 1995; Treisman, 1988; Wolfe, Butcher, Lee, & Hyle, 2003). Instead of keeping the target identity the same across trials, the identity of the target varies across trials. For example, the target may be either a red horizontal line or a green horizontal line among a variable number of gray horizontal lines (within-dimensional search), or the target may be either a red horizontal line or a gray vertical line among gray horizontal lines (cross-dimensional search). The consequence of varying the target identity randomly across trials is that participants do not know what target is going to be presented on the next trial. Usually, feature value uncertainty is compared with dimensional uncertainty.

Treisman (1988) was the first to investigate these two types of uncertainty. In a within-dimensional search condition, the target dimension was constant (e.g., orientation), but the target feature value was unpredictable (left oriented, right oriented, or horizontal). In a cross-dimensional search condition, the target dimension was unpredictable (color, orientation, or size), but the feature value within a particular dimension was constant (e.g., in color dimension, the target is always red). A cross-dimensional cost of about 100 ms was found relative to within-dimensional search. Müller et al. (1995) replicated the cross-dimensional cost and explained their findings by assuming that pop-out target detection must be based on the output of dimension-specific saliency maps. Furthermore, Found and Müller (1996) described a dimension-specific intertrial facilitation effect: If a target was preceded by a target defined along the same dimension, then detection was faster relative to a preceding target defined along a different dimension. To explain these effects, Müller and colleagues (Krummenacher, Müller, & Heller, 2001, 2002; Müller et al., 1995; Müller, Reimann, & Krummenacher, 2003) proposed a *dimensional-weighting* account of visual search, according to which master map units compute the weighted sum of dimension-specific saliency signals in parallel. If the dimension of the target is known in advance, then that dimension is assigned a larger weight than the other dimensions, allowing a faster detection of the target. However, if the target-defining dimension is not known in advance, then a particular dimension cannot be given preferential treatment, and thus the master map salience signal may stay longer below threshold required for

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response. Thus, fast target detection requires that the target dimension be weighted sufficiently to amplify the saliency signal generated within this dimension above the detection threshold. Dimension change incurs a cost because attentional weight must be shifted from the old to the new dimension.

Müller and colleagues also found, besides a dimension-specific intertrial effect, a feature-specific intertrial effect for color targets: Detection of a color singleton (e.g., red) was facilitated when a color singleton defined by the same color (red) was detected in the previous search trial(s) relative to when another color singleton (e.g., blue) was detected (see also Hillstrom, 2000; Kumada, 2001). They explained this by dividing the color dimension in relatively independent subdimensions, each computing feature contrast within separate "wavelength" channels. The dimensional-weighting account can be applied in these subdimensions in the same way as in the broader dimensions, for example, in the dimension shape (Found & Müller, 1996).

In line with these results, Maljkovic and Nakayama (1994) have also demonstrated feature-specific intertrial effects for color targets. They referred to this phenomenon as *priming of pop-out*. Maljkovic and Nakayama (1994) showed that even though participants knew the upcoming target feature, this did not influence the repetition effect. They argued that these repetition effects are passive and autonomous and not influenced by top-down control. However, Hillstrom (2000) found as well a feature-specific intertrial effect but with faster responses to trials in an alternating sequence (in which the participants knew the color of the target on each trial) relative to a random sequence. This suggests that there can be a top-down modulation on the feature repetition effect. Indeed, in Müller et al.'s (2003) recent study, participants were precued either to the most likely target-defining dimension or to the most likely feature value. This trial-by-trial cueing procedure reduced, but did not abolish, the intertrial effects. Müller and colleagues argued that top-down dimensional control can modulate stimulus-driven processes in the detection of pop-out signals.

Closely related to the dimensional-weighting theory is the guided search account of Wolfe (1994). Guided search assumes that visual stimuli are analyzed into basic features in different dimension-specific modules (e.g., color, orientation). The activation for each stimulus is calculated, separately in each dimension module. This activation is based on differences between the items (bottom-up) and on task demands (top-down). These activations are summed onto an activation map. In visual search, focal attention is guided to the location with the most activation.

In a recent study, Wolfe et al. (2003) investigated the contributions of top-down and bottom-up processes in feature search tasks by means of varying the uncertainty about the target's feature value and dimension. They used a fully mixed condition in which both the target dimension and the target feature value were uncertain from trial to trial. Also, items that were targets on one trial can appear as distractors on another. For example, on one trial, the target could be a red horizontal line, with green horizontal lines as distractors, whereas on a next trial, the target could be a green horizontal line, with red horizontal lines as distractors. This method increased uncertainty about the feature and dimension of the target in order to obtain less top-down information. Note that Wolfe et al. (2003) used the term *top-down guidance* even though this effect is typically referred to as *stimulus identity priming* (e.g., Posner, 1978). Wolfe et al. (2003) reasoned that implicit knowledge of what happened on a previous trial can help tune the sensory systems for the next trial. Whereas Wolfe and colleagues concluded that these intertrial effects were the result of top-down guidance, Maljkovic and Nakayama (1994) considered these very same effects as the result of passive bottom-up priming and not influenced by top-down control.

Wolfe et al. (2003, Experiment 3) showed that intertrial effects are based more strongly on target than on distractor identity. Furthermore, the results revealed a cost for cross-dimensional relative to within-dimensional search. Wolfe and colleagues suggested that these RT differences may be based on the salience of the difference between the target and the nontargets. The activation of the target is considered as the signal; the activation of the nontargets is considered as distracting noise. This signal-to-noise ratio (S/N ratio) is a hypothetical measure of the size of the signal guiding attention to the target among its nontargets. Top-down processes act to set weights to optimize the S/N ratio. In a cross-dimensional condition, all features are comparable and thus receive equal weight. In a within-dimensional condition, however, one dimension receives the strongest weight. Consequently, this gives an advantage to the within-dimensional condition.

Cohen and Magen (1999) suggested another explanation for the cross-dimensional cost. They argued that this effect reflects response stage processes and not perceptual processes, as proposed by Müller and colleagues (Found & Müller, 1996; Müller et al., 1995) and Wolfe et al. (2003). They also compared within- and cross-dimensional search. However, they changed the stimulus-to-response mapping from a present–absent task (as in Müller et al., 1995) to a discrimination task (either between two features in one dimension or between two dimensions). They reasoned that if perceptual processes caused the difference between the two conditions, then a different stimulus-to-response mapping should not affect the cross-dimensional cost. Instead, if such a difference would be obtained, then the results should be attributed to response selection processes. Cohen and Magen (1999) found that the typical cross-dimensional cost disappeared. In fact, in some conditions, cross-dimensional search was even more efficient as was within-dimensional search. To explain these results, they refer to the response selection model of Cohen and Shoup (1997). In this model, visual stimuli are analyzed into features in different dimension maps (see also Cave & Wolfe, 1990; Cohen, 1993; Treisman & Sato, 1990). More importantly, they assume that after visual selection, the response assignments to single features are determined separately within each dimension module. In other words, there is not a single response selection mechanism, but there is one for each dimension module (see also Mordkoff & Yantis, 1993). Recently, the model was expanded by Cohen and Feintuch (2002), resulting in a visual system linking perception and action, referred to as the *dimensional action system*. However, these results can also be explained by the dimensional-weighting theory. In the intradimensional task, the target's identity had to be determined, whereas in the cross-dimensional task, only the target's dimension was necessary for a correct response. This resulted in an advantage for the cross-dimensional condition. This was also pointed out by Cohen and Magen (1999, p. 306).

The aim of this study was to distinguish between a search-based account and a response-based account. Guided search (Wolfe et al., 2003) assumes that cross-dimensional costs and intertrial facilitation are because of speeding up or slowing down the actual search for the singleton target. In other words, this theory assumes that the within-dimensional search is faster because the actual search for the feature target becomes faster. Also, intertrial facilitation occurs because the search for the singleton target is speeded. Recent work by Theeuwes, Reimann, and Mortier (in press) suggests that these effects may have nothing to do with actual search. In the present study, we examined cross-dimensional costs and intertrial facilitation (dimension specific or feature specific) in conditions in which there was no search. If these effects occur in a nonsearch task, then this would indicate that these effects cannot be attributed to search processes. If these effects are not present when the search component is removed, then it is fair to argue that cross-dimensional costs and intertrial facilitation are related to the actual search process.

In Experiments 1 and 2, participants had to perform either a visual search task, that is, search for a within- or cross-dimensional target element, or a nonsearch task, that is, respond to a within- or cross-dimensional target element presented at the center of the visual field. In Experiments 3 and 4, we used a trial-by-trial cueing procedure in a nonsearch task.

Experiment 1

We examined whether a cross-dimensional cost was specific for search processes. One way to determine this is to eliminate search. Consequently, there is no need to guide attention to the target. We compared a classic feature search task, in which participants have to discern the presence or absence of the target, with a nonsearch task. In this nonsearch task, only one stimulus is presented, and participants had to indicate whether the stimulus is a target or not. Both tasks had two conditions: a within-dimensional condition, in which the dimension of the target is known in advance, and a cross-dimensional condition, in which the dimension of the target is uncertain.

Method

Participants

Eight undergraduates, ranging in age from 19 to 23 years, participated as paid volunteers. All participants had normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

Apparatus and Stimuli

Participants were seated in front of a computer monitor with their heads fixed on a chinrest. Viewing distance was approximately 75 cm. All participants were instructed not to move their eyes during the trials. The display background was black (0.6 cd/m^2). In the search task, the display contained stimuli on an imaginary circle drawn around the center of the display, with a radius of 3.6° of visual angle. The display set size consisted of three, six, or nine items. The position of each element was randomly chosen, the only restriction being that distances between neighboring display elements were equal.

In the nonsearch task, the display contained only one stimulus, which appeared randomly on the imaginary circle to keep the displays similar. Both tasks had two conditions, a within-dimensional condition and a cross-dimensional condition. In the within-dimensional condition, the target was a colored circle, either yellow, green, or red. In the cross-dimensional condition, the target could be either a gray triangle (shape), a big gray circle (size), or a red circle (color). The nontargets in the search task were gray circles. A target-absent trial in the nonsearch task was one gray circle. All stimuli (yellow, green, red, and gray) were equiluminant (approximately 9.0 cd/m^2).

Procedure

Participants began each trial by fixating a central fixation cross. After 700 ms, the stimulus display was presented for 200 ms on a black background (see Figure 1). Participants had 2 s to respond. The intertrial interval was 800 ms. The three possible targets were mapped onto one response button, and the target-absent trials were mapped onto the other response button. Participants were told to respond as quickly as possible with either left response (*z* button) or right response (/ button). When the participants made an error, a tone (300 Hz) was presented for 100 ms.

Design

All participants were included in the search and the nonsearch task. These two tasks were blocked and presented in counterbalanced order. Each task consisted of two conditions, a within-dimensional condition and a cross-dimensional condition. For each task, the conditions were also blocked and presented in counterbalanced order. Each task consisted of 1,080 experimental trials, with each condition comprising 540 trials. Each condition comprised six experimental blocks, with each block consisting of 90 trials. For each condition, there were 270 target-present trials and 270 target-absent trials. On the target-present trials, each of the three targets was presented equally often. Only in the search task was the display size varied, with the three display sizes presented equally often. Within each condition, all types of trials were randomly varied. Participants received 18 practice trials before each condition. At the end of each block, there was a short break during which the participants received feedback on their accuracy and RTs. The response mapping was counterbalanced across participants.

Results

RTs of incorrect responses in response to the red target (4.76%) and RTs longer than 1,100 ms (0.04%) were excluded from the analysis.

RTs

The main interest is the comparison of mean RTs for the identical target present in the within-dimensional condition and cross-dimensional condition: the response to the red circle. Only the data in response to this target were analyzed.

First, we determined whether, in the search task, search for the red target was performed in parallel. An analysis of variance (ANOVA) was performed on the mean RTs in the search task, with display size and condition as within-subjects factors. There was no display size effect, $F(2, 14) = 0.32$, $p = .73$, with the average slope being 0.7 ms per item, indicating that the search task was indeed a pop-out search task. There was a main effect of condition, $F(1, 7) = 33.28$, $p < .01$. There was a significant interaction between display size and condition, $F(2, 14) = 5.74$, $p < .05$. Note, however, that this interaction is only because of the deviating pattern at Display Size 3, in which RTs for the cross-dimensional condition were longer than for the other display sizes, whereas in the within-dimensional condition, the RTs were shorter with Display Size 3 relative to the other display sizes. If Display Size 3 was excluded from the analysis, then there was no significant interaction ($F < 1$) (see Figure 2).

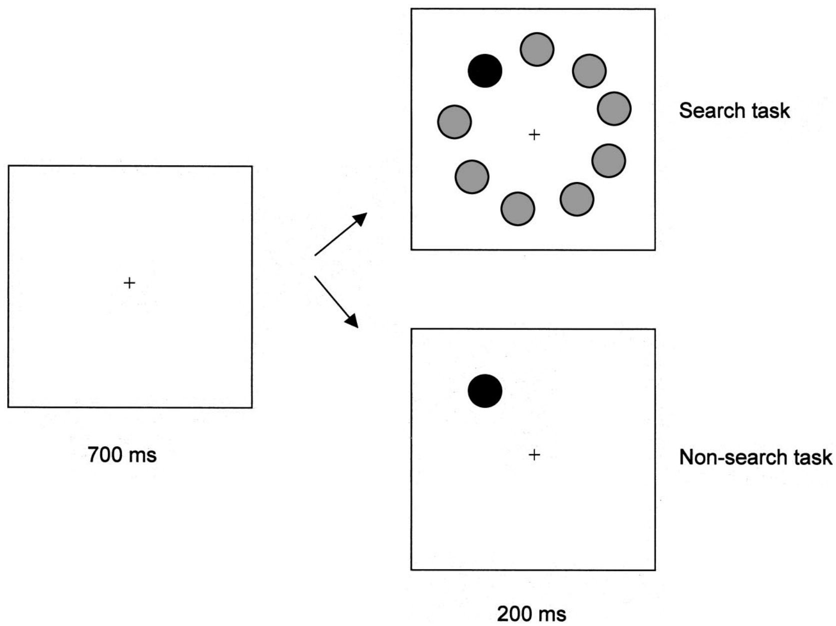

Figure 1. An example of a trial sequence in the search task and nonsearch task of Experiment 1. The fixation cross was presented for 700 ms, followed by the stimulus display, presented for 200 ms on a black background. Participants had 2 s to respond.

Second, a repeated measures ANOVA was performed on the individual mean RTs of the target-present trials, with task (search or nonsearch) and condition (within dimension or across dimensions) as within-subjects factors. Because only the red circle was present in both conditions, we analyzed only these results. The main effect of task was not significant, $F(1, 7) = 1.06$, $p = .34$. Importantly, there was a main effect of condition, $F(1, 7) = 71.73$, $p < .0001$. The Task × Condition interaction was not significant, $F(1, 7) = 0.34$ (see Figure 3).

A separate analysis was performed on the target-absent trials, with task and condition as within-subjects factors. There was no main effect of task ($F < 1$) (search task: 407 ms, nonsearch task: 406 ms). There was a main effect of condition, $F(1, 7) = 89.17$, $p < .001$, with longer RTs in the cross-dimensional condition (439

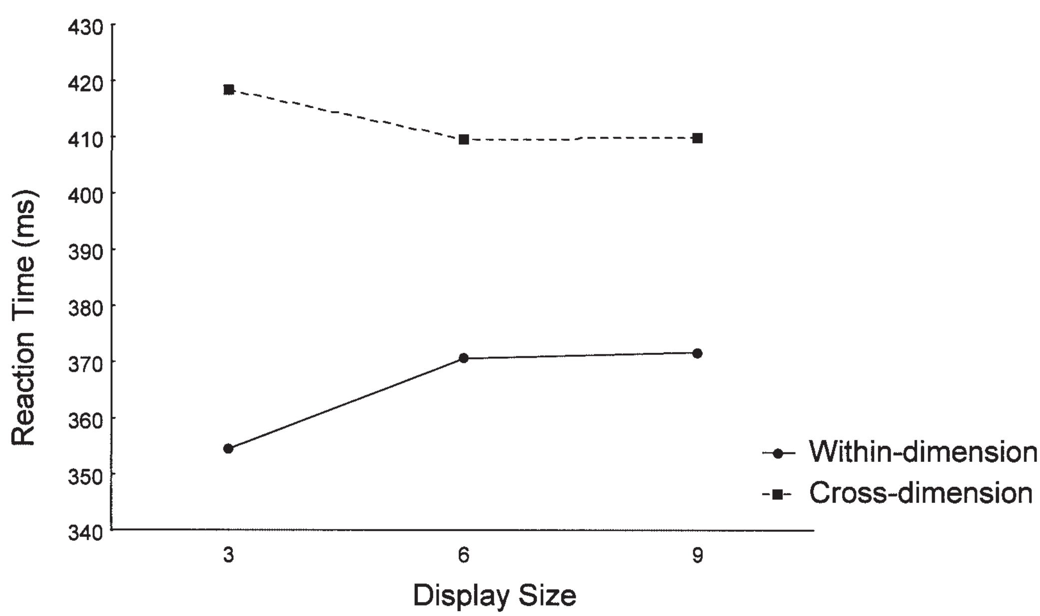

Figure 2. Experiment 1: Mean reaction times for target-present trials in the search task as a function of condition (within dimension or cross-dimension) and display size (3, 6, or 9).

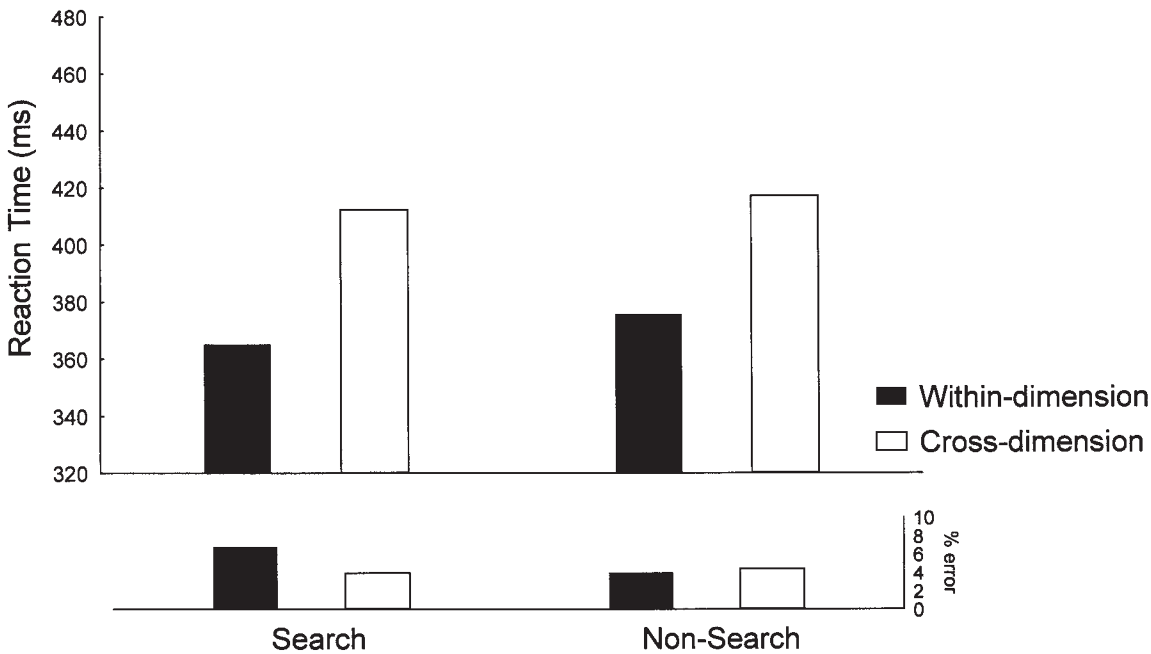

Figure 3. Experiment 1: Mean reaction time for target-present trials as a function of condition (within dimension or cross-dimension) and task (search or nonsearch).

ms) relative to the within-dimensional condition (374 ms). The Task × Condition interaction was not significant, $F(1, 7) = 1.74$, $p > .05$.

Intertrial Effects

An ANOVA was performed on the trials containing the red circle as target, with task (search or nonsearch), condition (within dimension or across dimensions), and intertrial transition (same target or different target on the previous trial) as within-subjects factors. Trials in which the previous trial was a target-absent trial were excluded.

There was a main effect of condition, $F(1, 7) = 46.76$, $p < .001$ (within dimensional: 374 ms, cross-dimensional: 412 ms). There was no effect of task, $F(1, 7) = 1.11$, $p = .33$ (search: 389 ms, nonsearch: 397 ms). Importantly, there was a main effect of intertrial transition, $F(1, 7) = 17.47$, $p < .01$, with target-repeating trials (382 ms) being faster than target-alternating trials (404 ms). There were reliable interactions between intertrial transition and condition, $F(1, 7) = 11.26$, $p < .05$, and between intertrial transition and task, $F(1, 7) = 5.52$, $p = .05$. There was a significant three-way interaction between condition, task, and intertrial transition, $F(1, 7) = 19.32$, $p < .01$. Planned comparisons showed that there was no significant difference between target-repeating trials (379 ms) and target-alternating trials (381 ms) in the within-dimensional condition of the nonsearch task, $F(1, 7) < 1$, whereas there was a significant difference between the target-repeating trials (387 ms) and the target-alternating trials (439 ms) in the cross-dimensional condition of the nonsearch task, $F(1, 7) = 26.70$, $p < .01$. In the search task, there was a significant difference between target-repeating trials and target-alternating trials for both the within-dimensional condition, $F(1, 7) = 7.13$, $p < .05$ (target-repeating trials: 361 ms, target-alternating trials: 374 ms), and the cross-dimensional condition, $F(1, 7) = 7.80$, $p < .05$ (target-repeating trials: 402 ms, target-alternating trials: 422 ms).

Error Analysis

The total number of errors in response to the red circle and to target-absent trials was 4.8% (target misses = 4.76%, false alarms = 4.85%). The errors were calculated for each condition of each task for each participant. An ANOVA was performed on these totals, with type of error (target miss or false alarm), task, and condition as within-subject variables. There were no main effects: type of error, $F < 1$; task, $F(1, 7) = 2.04$, $p = .20$; condition, $F < 1$. Only the interaction between type of error and condition was significant, $F(1, 7) = 16.24$, $p < .01$, with more target misses (5.3%) and fewer false alarms (4.2%) in the within-dimensional condition than in the cross-dimensional condition (target misses = 4.2%, false alarms = 5.5%). Therefore speed–accuracy trade-off effects were not apparent in the data.

Discussion

Relative to responding to a target for which the dimension is known but the feature value is not known, a cost was found in the feature search task for responding to a target for which the dimension is uncertain. In other words, if participants had to search for a target, then they were faster to detect the target if they knew the dimension in advance. These results basically replicate previous obtained results (e.g., Müller et al., 1995; Treisman, 1988). More importantly, however, exactly the same results were obtained in the condition in which there was nothing to search. In the nonsearch condition, there was only one element in the display, and exactly the same cross-dimensional costs were found. Indeed, the interaction between type of task (search vs. nonsearch) and condition (cross-dimensional vs. within dimensional) was not reliable ($F < 1$), and the 48-ms cost in the search task was comparable with the 42-ms cost in the nonsearch task. It may be that the main effect of task was obscured because half the participants first performed the search task and then the nonsearch task, and half in reverse order. In the nonsearch task, the aim was to identify the color of the target in order to discriminate it from the nontarget. In the search task, however, only detection of the target was needed. It could be that the participants who first performed the nonsearch task carried over this identity analysis to the search task. If this were the case, then it would be difficult to find an effect of task. However, there was no reliable difference, not even a tendency, between this group and the group that first performed the search task ($F < 1$).

RTs were shorter if the target was repeated relative to when the target was different from the previous trial. This effect is similar to previous results (Found & Müller, 1996; Hillstrom, 2000). However, this effect was absent in the within-dimensional condition of the nonsearch task. It remains unclear why this absence occurred (see the results of Experiment 2, which did show this effect).

These results suggest that the cross-dimensional effect, as is typically found in visual search tasks, may have nothing to do with attentional guidance. However, one may argue that in Experiment 1, there was still some guiding of spatial attention in the nonsearch task. Indeed, the exact location of the single target element varied from trial to trial. Thus, even though there were no nontargets, one could claim that it was possible that attention was guided to the target. Experiment 2 was designed to investigate this issue.

Experiment 2

In Experiment 2, the uncertainty of the target location in the nonsearch task in Experiment 1 was removed. In this experiment, the target was always placed at the same location (i.e., in the middle of the screen). In this way, participants knew the location of the target, and there was no need for localizing the target.

Method

Participants

Eight undergraduates, ranging in age from 19 to 26 years, participated as paid volunteers. All participants had normal or corrected-to-normal vision and were naive as to the purposes of the experiment.

Apparatus, Stimuli, and Procedure

The apparatus was the same as in Experiment 1. The stimuli were the same as in the nonsearch condition of Experiment 1. The procedure was identical to the one in Experiment 1, with two changes. First, there was only a nonsearch task. Second, the target was always placed in the center of the screen.

Design

All participants were included in the within-dimensional condition and the cross-dimensional condition. These two conditions were blocked and presented in counterbalanced order. Participants received 18 practice trials before each condition. Each condition comprised four experimental blocks, with each block consisting of 45 trials. This resulted in a total of 360 experimental trials. For each condition, there were 90 target-present trials and 90 target-absent trials. On the target-present trials, each of the three targets were presented equally often. Within each condition, all types of trials were randomly varied. At the end of each block, there was a short break during which the participants received feedback on their accuracy and RTs.

Results

The analysis performed on the results was the same as in Experiment 1. Only the results of the response to the red circle were analyzed. RTs from incorrect response trials in response to the red circle (4.4%) and RTs more than 1,100 ms (0.4%) were excluded from the analysis.

RTs and Error Analysis

We compared the mean RTs of the responses to the red target in the within-dimensional (color) condition with those in the cross-dimensional condition by means of a paired t test. The average difference of 59 ms was significant, $t(7) = 3.8, p < .01$ (valid: 340 ms vs. invalid: 399 ms). As in Experiment 1, a strategy effect needs to be excluded. There was a main effect of type of trial (target present vs. target absent), $F(1, 7) = 18.58, p < .01$. However, the RTs for target-absent trials (391 ms) were longer relative to target-present trials (370 ms).

The total number of errors in response to the red circle and to target-absent trials was 5.2% (target misses = 4.4%, false alarms = 5.9%). The errors were calculated for each condition for each participant. An ANOVA was performed on these totals, with type of error (target misses or false alarms) and condition as within-subject variables. There were no main effects: condition, $F < 1$; type of error, $F(1, 7) = 2.59$, *ns*. The interaction was not significant ($F < 1$). This indicates that the results of the RTs cannot be attributed to a speed–accuracy trade-off. The RTs and error percentages of Experiment 2 are presented in Table 1.

Intertrial Effects

A two-way ANOVA was performed on the trials containing a red circle as target, with condition (within dimension or across dimensions) and intertrial transition (same target or different target on the previous trial) as within-subjects factors. Trials were excluded in which the previous trial was a target absent. There was a main effect of condition, $F(1, 7) = 18.90, p < .01$, which was also shown in the RT analysis. There was also a main effect of

Table 1
Mean Reaction Times (RTs) and Error Percentages for the Within-Dimensional Condition and the Cross-Dimensional Condition in Experiment 2

Nonsearch task	Mean RT	Error %	% false alarm
Within dimension	340	3.75	
Target-absent trial	366		5.0
Cross-dimension	399	5.80	
Target-absent trial	417		6.9

Note. Responses are to the red circle as target.

intertrial transition, $F(1, 7) = 9.89$, $p < .05$, with participants responding faster to target-repeating trials (342.5 ms) than to target-alternating trials (391.5 ms). The interaction was not significant, $F(1, 7) = 1.59$.

Discussion

Experiment 2 replicated the results of the nonsearch task of Experiment 1. A significant cost of 59 ms was found in responding to a target defined in an uncertain dimension relative to a known target dimension. The intertrial effect was significant for both the within-dimensional condition and the cross-dimensional condition. This is in contrast to Experiment 1, in which the intertrial effect was absent in the within-dimensional condition of the nonsearch task. It is unclear why this difference occurred.

Because the target was consistently located in the center of the screen, there was clearly no need to search. Taken together, the results of Experiments 1 and 2 show cross-dimensional costs and intertrial effects, as have been reported in previous studies (e.g., Found & Müller, 1996; Müller et al., 1995); yet, these effects occur in a task in which there is no need to guide attention to the target.

The presence of cross-dimensional costs and intertrial effects under conditions in which there is no search indicates that search processes are not necessary to induce these effects.

A general framework that can explain these findings both under search and nonsearch conditions is the dimensional action model of Cohen and Shoup (1997; see also Cohen & Magen, 1999). These findings indicate that when the dimension one has to respond to does not vary from trial to trial (i.e., the within-dimensional condition), the response selection mechanism of a particular dimension (in our case, color) may get primed by the previous trial. In the cross-dimensional condition, there is no priming of just one dimension-specific response selection mechanism because both the color-specific and the shape-specific response selection mechanisms were necessary to perform the task.

Even though these findings suggest that the previously reported cross-dimensional costs may have nothing to do with search processes, one may argue that active trial-by-trial dimensional cueing may allow participants to create a top-down setting that enables the facilitation of attentional guidance to the featural singleton. In a recent study, Müller et al. (2003) used a trial-by-trial dimensional-cueing procedure. Before each trial, a verbal cue (the words *color* and *shape*) indicated the likely target-defining dimension. It is assumed that the cue allows participants to actively prepare themselves for the likely upcoming stimulus dimension. In terms of the dimensional-weighting account (Müller et al., 2003), or guided search (e.g., Wolfe et al., 2003), it is assumed that participants use the advance cue to allocate attentional weight to the likely target dimension. In Experiments 3 and 4, we used the same trial-by-trial procedure as did Müller et al. (2003). However, instead of using a search task, we used a nonsearch task in which only one element was presented in the display.

Experiment 3

In Experiment 3, identical to Müller et al. (2003), a symbolic (verbal) cue indicated with 80% probability the dimension of a single stimulus, presented in the middle of the screen: *color* or *shape*. This resulted in two different types of trials: a valid dimension trial, in which the cue indicates validly the dimension of the target (e.g., the cue is *color*, and the target is a red circle), and an invalid dimension trial, in which the cue indicates a different dimension as the target dimension (e.g., the cue is *color*, and the target is a gray triangle). The main interests were the validity effects and the intertrial effects.

Method

Participants

Twelve undergraduates, ranging in age from 18 to 27 years, participated as paid volunteers. All participants had normal or corrected-to-normal vision and were naive as to the purposes of the experiment.

Apparatus and Stimuli

The apparatus was the same as in Experiment 1. The target could be a red or a green circle, a gray triangle or a gray square. The nontarget was a gray circle.

Procedure

Initially, a verbal cue (*color* or *shape*) was presented at the center of the screen for 700 ms (see Figure 4). The cue was replaced by a fixation cross. After 850 ms, the stimulus was presented in the center of the screen for 200 ms. Participants had 2 s to make a response. When the participants made an error, a tone (300 Hz) was presented for 100 ms. The intertrial interval was 800 ms. The task was to respond as quickly as possible to the target with either a left response (*z* button) or a right response (*/*). The four possible targets were mapped onto one response button, and the target-absent trials were mapped onto the other response button. The response mapping was counterbalanced across participants.

Design

Participants received 100 practice trials, followed by 20 experimental blocks, each consisting of 50 trials. There was a total of 1,000 experimental trials. Of the trials, 40% were target absent, and 60% were target present. On target-present trials, half the targets were defined in the color and half in the form dimension. The color targets were half red and half green; the form targets were half triangle and half square. On target-absent trials, a gray circle was presented. In target-present trials, the cue indicated with 80% probability the dimension of the target. All types of trials were randomly varied. At the end of each block, there was a short break during which the participants received feedback on their accuracy and RTs. The independent variables were target present and target absent and, for target-present trials, were cue validity (valid, invalid dimension), target dimension, and, depending on the target dimension, target feature value (red, green, square, triangle).

Results

RTs from incorrect responses to target-present trials (2.95%) and RTs more than 1,100 ms (0.2%) were excluded from the analysis.

RTs

The averaged mean RT for target-absent trials was 393 ms. A repeated measures ANOVA was performed on the individual mean RTs of the target-present trials, with cue validity (valid, invalid) and target dimension (color, shape) as within-subjects factors.

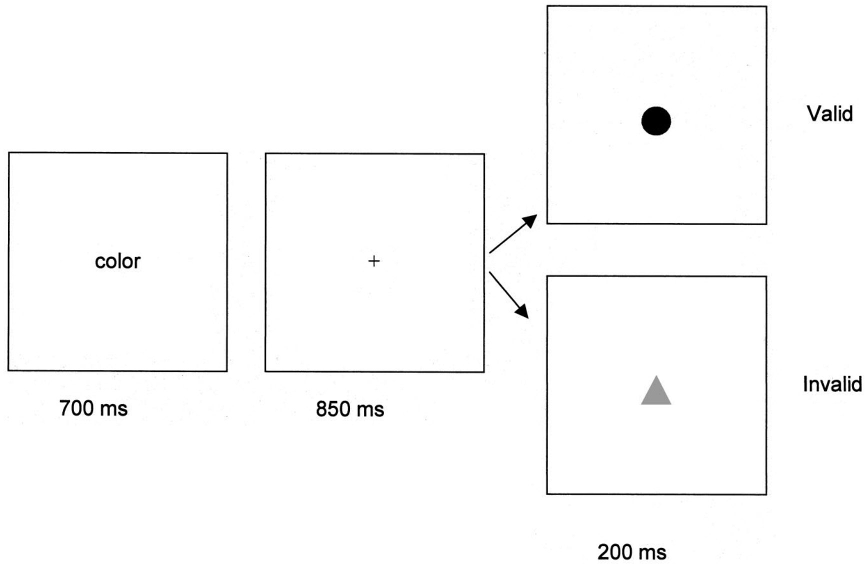

Figure 4. An example of a trial sequence in Experiment 3. A verbal cue indicated with 80% validity the dimension ("color" or "shape") of the single stimulus. The cue was presented during 700 ms, followed by the fixation cross, on a black background for 850 ms. The stimulus display was presented for 200 ms. Participants had 2 s to respond.

Both main effects were significant: cue validity, $F(1, 11) = 5.10$, $p < .05$, and target dimension, $F(1, 11) = 16.22$, $p < .01$. Color targets were detected faster than shape targets (380 ms vs. 399 ms), and RTs were shorter on valid relative to invalid trials (375 ms vs. 404 ms). There was no significant Cue Validity × Target Dimension interaction, $F(1, 11) = 1.48$, $p > .05$ (see Figure 5).

Intertrial Effects

An ANOVA was performed on the valid target-present trials, with target dimension (color, shape) and intertrial transition (same dimension, different dimension) as within-subjects factors. Note that only the valid trials were analyzed. For invalid trials, there were not enough trial transitions to perform a reliable analysis. Both target dimension, $F(1, 11) = 14.03$, $p < .01$, and intertrial transition, $F(1, 11) = 11.64$, $p < .01$, were significant. The Target Dimension × Intertrial Transition interaction approached significance, $F(1, 11) = 4.47$, $p = .06$. RTs to targets (on trial n), with the preceding trial ($n - 1$) containing a target defined in a different dimension (387 ms), were 21 ms longer than RTs to targets defined in the same dimension as in the preceding trial (366 ms). Planned

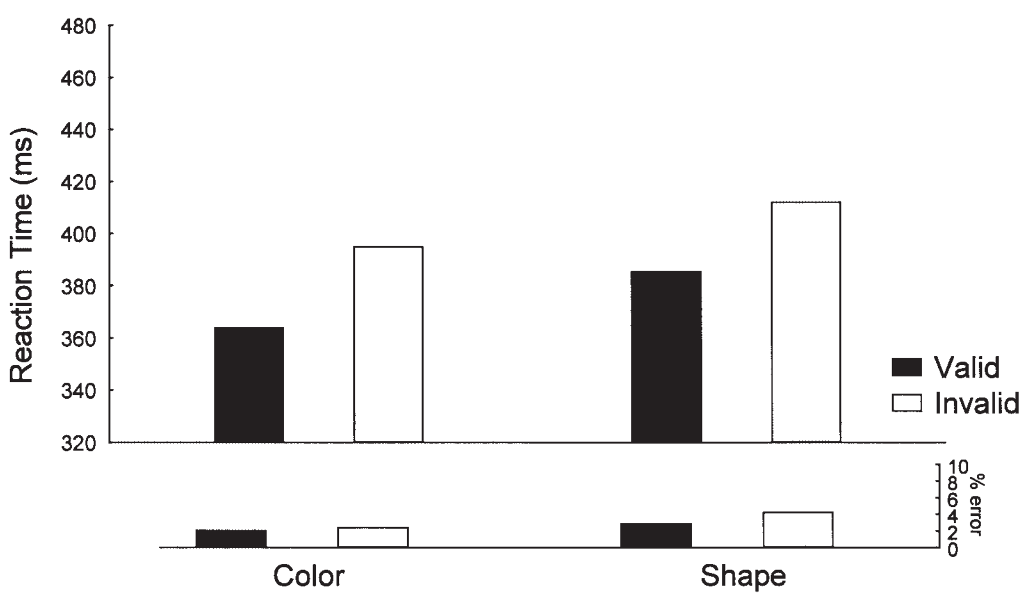

Figure 5. Experiment 3: Mean reaction times and error percentages for target-present trials as a function of cue validity (valid or invalid dimension) and target dimension (color or shape).

comparisons were performed to further examine these effects separately for color targets and shape targets.

For the color targets ($M = 367$ ms), irrespective of whether the target on trial $n - 1$ was defined by the same feature value (348 ms), $F(1, 11) = 14.71$, $p < .01$, or by a different feature value (358 ms), $F(1, 11) = 9.45$, $p < .05$, a dimension-change cost occurred, compared with RTs to color targets preceded by shape targets (380 ms). For the shape targets ($M = 386$ ms), this dimension-change cost was only caused by the trials in which the target was defined in a different feature value on the preceding trial (381 ms), $F(1, 11) = 8.21$, $p < .05$. If the target on trial $n - 1$ was defined in the same feature value as the target on trial n (377 ms), then there was no reliable difference with dimension-change trials (393 ms), $F(1, 11) = 2.71$, $p = .13$. For both color targets and shape targets, feature repetition trials were not significantly faster than feature alternation trials: color, $F(1, 11) = 4.51$, $p = .06$; shape, $F(1, 11) = 0.17$, $p = .69$. In other words, there was no feature-specific intertrial facilitation effect, although for the color targets, it was marginally significant.

Error Analysis

A repeated measures ANOVA was performed on the target-miss rates (2.95%), with cue validity (valid, invalid) and target dimension (color, shape) as within-subjects factors. Only the factor target dimension was significant, $F(1, 11) = 10.83$, $p < .01$, with more errors in response to shape targets (3.6%) relative to color targets (2.3%). This mimics the RT data. There was no effect of cue validity ($F < 1$). The Target Dimension × Cue Validity interaction was not significant ($F < 1$). There was a 5% false-alarm rate.

Discussion

The results of Experiment 3 showed that top-down modulation and bottom-up effects can be found in a nonsearch task. Typically, color targets are detected faster than shape targets. This finding corresponds to previous observations (Found & Müller, 1996; Hillstrom, 2000; Müller et al., 1995; Olivers & Humphreys, 2003). Symbolic cueing of the likely target dimension produced significant RT benefits for valid relative to invalid cue trials (29-ms benefit). With valid dimension cues, there was a dimension-specific intertrial effect of 21 ms.

The present findings are basically the same as those reported by Müller et al. (2003). A valid cue provided shorter RTs than invalid cues. The authors found a comparable cue-validity effect of 21 ms. Also, they found a dimension-specific intertrial effect of 10 ms for valid cue trials. Even though the cueing effects and intertrial effects were basically the same as in Müller et al., in the present task, there was no search whatsoever. The target element was always presented in the center of the screen. Again, in line with our Experiments 1 and 2, the cueing effect that Wolfe et al. (2003) would interpret as evidence for intentional top-down guidance of the visual search process may have nothing to do with visual search because in our task, there was no search to perform.

Note that there was no feature-specific intertrial effect. However, for the color targets, the difference between feature-repetition trials and feature-alternation trials was almost reliable (see also Found & Müller, 1996; Maljkovic & Nakayama, 1994). This lack of a feature-specific intertrial effect (except for color) was also found in Müller et al.'s (2003) study.

Experiment 4

According to the dimensional-weighting account (Müller et al., 2003), cues should speed up processing of a particular dimension rather than a specific feature value. Experiment 4 examined whether a valid feature cue (e.g., the cue is *red*, and the target is a red circle) would speed the response relative to an invalid same-dimension cue (e.g., the cue is *green*, and the target is a red circle). Whereas in Experiment 3, the cue indicated the likely dimension of the upcoming target, in Experiment 4, the cue indicated with 80% probability the likely feature value of the upcoming target. This resulted in three types of trials: either a valid trial, in which the cue indicated the feature value of the target, an invalid same-dimension trial, in which the cue indicated the correct dimension of the target but cued another feature value as that of the target, or an invalid different-dimension trial, in which the cue indicated another dimension than did the target dimension.

Method

Participants

Ten undergraduates, ranging in age from 19 to 30 years, participated as paid volunteers. All participants had normal or corrected-to-normal vision and were naive as to the purposes of the experiment.

Apparatus and Stimuli

The apparatus and stimuli were the same as in Experiment 3.

Procedure

The procedure was the same as in Experiment 3, except that the verbal cue now reflected the feature value of the target: *red*; *green*; *square*; or *triangle*.

Design

Participants received two practice blocks, followed by 20 experimental blocks. Each block comprised 50 trials. There was a total of 1,000 experimental trials. Of the trials, 40% were target absent, and 60% were target present. On target-present trials, half the targets were defined in the color and half in the form dimension. The color targets were half red and half green; the form targets were half triangle and half square. On target-absent trials, a gray circle was presented. The cue indicated with 80% probability the feature value of the target in the target-present trials. All types of trials were randomly varied. At the end of each block, there was a short break during which the participants received feedback on their accuracy and RTs. The independent variables were target present and target absent and, for target-present trials, were cue validity (valid, invalid same dimension, invalid different dimension), target dimension, and, depending on the target dimension, target feature (red, green, square, triangle).

Results

RTs from incorrect responses to target-present trials (4.47%) and RTs more than 1,100 ms (0.03%) were excluded from the analysis.

RTs

The averaged mean RT for target-absent trials was 391 ms. A repeated measures ANOVA was performed on the individual mean RTs of the target-present trials, with cue validity (valid, invalid same dimension, invalid different dimension) and target dimension (color, shape) as within-subjects factors. The main effect of cue validity was significant, $F(2, 18) = 14.19$, $p < .001$, with valid trials being detected faster (343 ms) than invalid different-dimension trials (412 ms) and invalid same-dimension trials (391 ms) were in between. There was also a main effect of target dimension, $F(1, 9) = 23.86$, $p < .001$: Color targets (371 ms) were detected faster than shape targets (393 ms). There was no significant Cue Validity × Target Dimension interaction ($F < 1$) (see Figure 6).

Planned comparisons were performed to further examine these effects. Relative to valid trials, there was a significant cost for invalid same-dimension trials, $F(1, 9) = 10.77$, $p < .01$, and for invalid different-dimension trials, $F(1, 9) = 15.91$, $p < .01$. In other words, there was a feature-specific cueing effect. Also, there was a dimension-specific cueing effect, with invalid same-dimension trials significantly faster than invalid different-dimension trials, $F(1, 9) = 27.19$, $p < .001$. When the cue indicated the correct target dimension, targets were detected faster than when the cue indicated the incorrect target dimension, $F(1, 9) = 19.40$, $p < .01$.

The same pattern was found for color trials and shape trials separately. Invalid same-dimension trials were slower than valid trials: color, $F(1, 9) = 9.16$, $p < .05$; shape, $F(1, 9) = 11.62$, $p < .01$; but faster than invalid different-dimension trials: color, $F(1, 9) = 29.78$, $p < .001$; shape, $F(1, 9) = 7.85$, $p < .05$. Invalid different-dimension trials were slower than valid trials: color, $F(1, 9) = 16.08$, $p < .01$; shape, $F(1, 9) = 14.69$, $p < .01$. When the cue indicated the correct target dimension, targets were detected faster than when the cue indicated the incorrect target dimension: color, $F(1, 9) = 21.49$, $p < .01$; shape, $F(1, 9) = 14.58$, $p < .01$.

Intertrial Effects

An ANOVA was performed on the valid target-present trials, with target dimension and intertrial transition (same feature, same dimension, different dimension) as within-subjects factors. Both main effects were significant: target dimension, $F(1, 9) = 14.53$, $p < .01$; with color targets (330 ms) being detected faster than shape targets (354 ms) and intertrial transition, $F(1, 9) = 9.37$, $p < .01$; with feature repetition trials (338 ms) being detected faster than trials with the target defined in a different feature value than the previous trial (336 ms), and both trials detected faster than trials with a target defined in a different dimension than the previous trials (351 ms). The Target Dimension × Intertrial Transition interaction was not significant, $F(2, 10) = 0.99$, *ns*.

Planned comparisons were performed to analyze dimension and feature change effects. There was no significant difference between feature-repetition and feature-alternation trials ($F < 1$). In other words, there was no feature-specific priming effect. In contrast, there was a dimension-specific priming effect: Relative to trials with a dimension change, dimension-repetition trials with feature repetition, $F(1, 9) = 8.46$, $p < .05$, and with feature alternation, $F(1, 9) = 17.60$, $p < .01$, were detected faster.

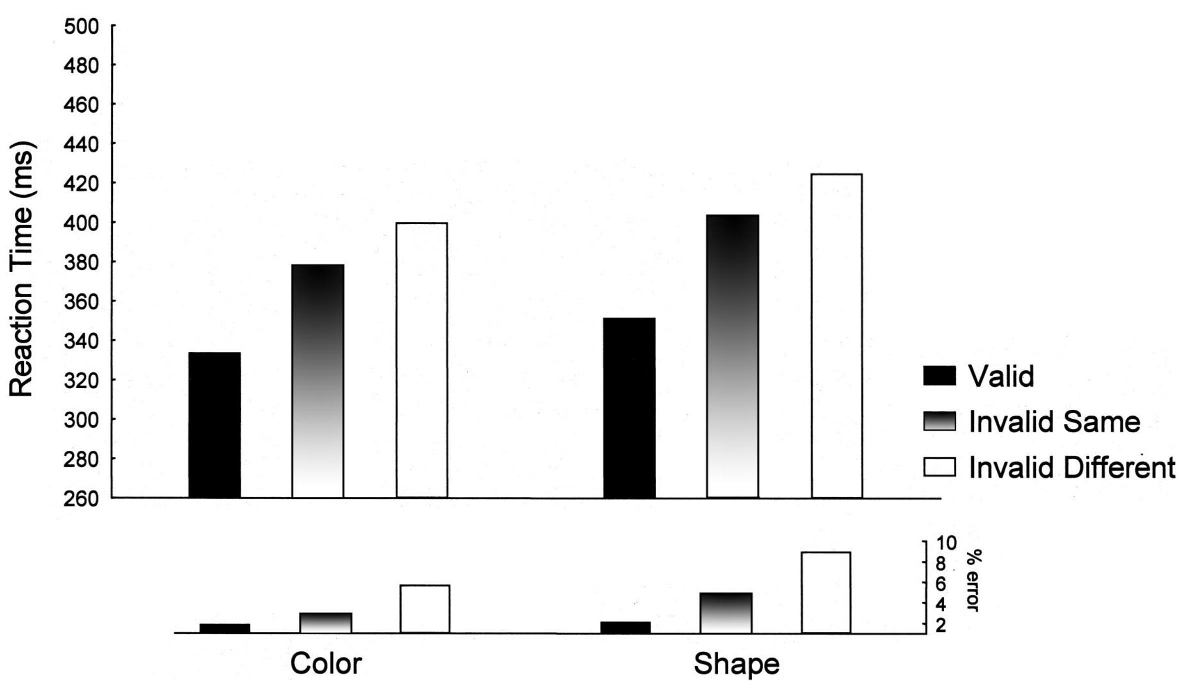

Figure 6. Experiment 4: Mean reaction times and error percentages for target-present trials as a function of cue validity (valid, invalid same dimension, invalid different dimension) and target dimension (color or shape).

Error Analysis

A repeated measures ANOVA was performed on the target-miss rates (4.47%), with cue validity (valid, invalid same dimension, invalid different dimension) and target dimension (color, shape) as within-subjects factors. Only the factor cue validity was significant, $F(2, 18) = 9.69$, $p < .01$, with more errors in response to invalid different-dimension trials (7.4%) relative to valid-dimension trials (2.0%) and the percentage of errors in invalid same-dimension trials (4.0%) in between. This mimics the RT data. There was no effect of target dimension, $F(1, 9) = 1.70$, *ns*. The Target Dimension × Cue Validity interaction was not significant, $F(2, 18) = 1.10$, *ns*. There was a 4.3% false-alarm rate.

Discussion

As in Experiment 3, there was a cue validity effect. Valid cueing resulted in faster detection of the target relative to invalid cueing. There was a dimension-specific cueing effect as a result of faster detection of the trials, with the same dimension as the cue, but another feature value relative to trials with another dimension, as the cue indicated. There was also a feature-specific cueing effect, with valid feature-cued trials being detected faster than trials that were cued with a valid dimension but an invalid feature value. Although the intertrial effects did not show a feature-specific intertrial effect (for a feature-specific intertrial effect, see Found & Müller, 1996; Maljkovic & Nakayama, 1994), there was a dimension-specific intertrial effect. Again, we found that color targets were detected faster than shape targets.

It is clear that cross-dimensional costs and intertrial effects can be found in tasks without a need for guiding spatial attention. It is not clear, however, what the nature is of these effects. Are they more perceptual in nature, as Müller and Wolfe and their colleagues suggested? Or, are they based on response selection processes, as Cohen and colleagues suggested? The next experiment was designed to make an attempt to disentangle these two hypotheses.

Experiment 5

Experiment 5 tested whether the cross-dimensional cost and the intertrial effects are related to perceptual or response selection factors. The nonsearch task of Experiment 2 was used with the addition of a compound nonsearch task. It is called a *compound* task because the to-be-reported attribute of the stimulus is not the same as the defining attribute of the stimulus (cf. Duncan, 1985). In this compound nonsearch task, participants had to respond to a line presented inside the stimulus. This line could be either vertical (e.g., press left) or horizontal (e.g., press right). It was assumed that if the cross-dimensional cost and the intertrial effects are perceptual in nature, then the effects would also be present in the compound nonsearch task because only the response requirements were changed. In contrast, if these effects were to disappear in the compound nonsearch task, then it would be fair to attribute these effects to nonperceptual processes such as response selection processes.

Method

Participants

Twenty-four undergraduates, ranging in age from 16 to 29 years, participated as paid volunteers. All participants had normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

Apparatus and Stimuli

The apparatus and stimuli were the same as in Experiment 2, except for a few changes. There were two different tasks. One task was a replication of the nonsearch task of Experiment 2, a detection nonsearch task, with the only difference being that the stimuli contained vertical and horizontal lines, which participants had to ignore. In the compound nonsearch task, the participants had to determine whether the line, presented inside the stimuli, was either vertical or horizontal.

Procedure

The procedure was the same as in Experiment 2, except that the stimulus display was presented until response. Participants had 2 s to respond.

Design

Half the participants completed the detection nonsearch task, and the other half completed the compound nonsearch task. Both tasks had two conditions, a within-dimensional condition and a cross-dimensional condition (see Experiments 1 and 2), which were presented in counterbalanced order. Participants received 50 practice trials before each condition. Each condition comprised nine experimental blocks, with each block consisting of 40 trials. This resulted in a total of 720 experimental trials. In the detection task, for each condition, there were 180 target-present trials and 180 target-absent trials. On the target-present trials, each of the three targets was presented equally often. Within each condition, all types of trials were randomly varied. In the compound task, in each condition, there were 180 trials with a vertical line and 180 trials with a horizontal line. At the end of each block, there was a short break during which the participants received feedback on their accuracy and RTs. The response mapping was counterbalanced across participants.

Results

The analysis performed on the results was the same as in Experiments 1 and 2. Only the results of the response to the red circle (either to the line presented inside or to the circle itself) were analyzed. RTs from incorrect response trials in response to the red circle (3.30%) and RTs more than 1,100 ms (0.64%) were excluded from the analysis.

RTs

A repeated measures ANOVA was performed on the individual mean RTs of the target-present trials, with task (compound task or detection) as a between-subjects factor and condition (within dimension or across dimensions) as a within-subjects factor. There was no main effect of task ($F < 1$). There was an effect of condition, $F(1, 22) = 32.40$, $p < .001$. The Task × Condition interaction was also significant, $F(1, 22) = 20.83$, $p < .001$. Planned comparisons showed that the effect of condition was present only in the detection task, $F(1, 22) = 52.59$, $p < .001$, but absent in the compound task ($F < 1$) (see Figure 7).

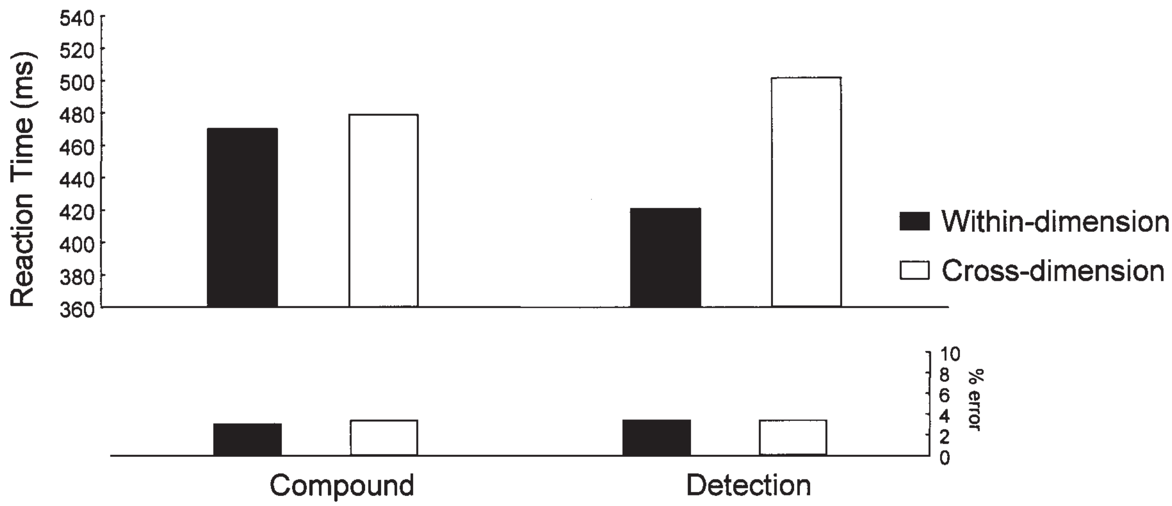

Figure 7. Experiment 5: Mean reaction times and error percentages as a function of task (compound or detection) and condition (within dimension or cross-dimension).

Intertrial Effects

An ANOVA was performed on the trials with a red circle as target, with task (compound task or detection), condition (within dimensions or across dimensions), and intertrial transition (same target or different target) as within-subjects factors. The trials on which the previous trial was a target-absent trial were excluded from the analysis. There was no main effect of task, $F(1, 22) = 1.26$, $p = .27$. The effect of condition was significant, $F(1, 22) = 17.38$, $p < .001$ (within dimensional: 439 ms, cross-dimensional: 483 ms). There was a main effect of intertrial transition, $F(1, 22) = 49.01$, $p < .001$ (same target: 448 ms, different target: 474 ms). All the interactions were reliable: the Task $\times$ Condition interaction, $F(1, 22) = 11.03$, $p < .01$; the Task $\times$ Intertrial Transition interaction, $F(1, 22) = 43.61$, $p < .001$; and the Condition $\times$ Intertrial Transition interaction, $F(1, 22) = 7.34$, $p < .05$. The three-way Task $\times$ Condition $\times$ Intertrial Transition interaction was also significant, $F(1, 22) = 9.28$, $p < .01$. Planned comparisons showed that the intertrial effect was absent in the compound task ($F < 1$) but present in the detection task, $F(1, 22) = 92.54$, $p < .01$. In the detection task, the intertrial effect was present for both conditions: within dimensional, $F(1, 22) = 25.16$, $p < .001$, and cross-dimensional, $F(1, 22) = 63.17$, $p < .001$ (see Figure 8).

Error Analysis

A repeated measures ANOVA was performed on the target-miss rates (3.4%) in response to the red circle with task (compound task or detection) and condition (within dimensions or across dimensions). There were no significant effects (Fs < 1). The false-alarm rate in the detection task was 3.13%, with no effect of condition ($F < 1$).

Discussion

This experiment was conducted to investigate whether the cross-dimensional effect and the intertrial effects were the result of perceptual or response selection factors. The detection and the compound task had the same visual stimulation; only the response demands were different. If the results of the two tasks are identical, then this means that the response requirements had no influence. However, if there are differences in the results, then this can only be because of the difference in response demands. The results showed a clear difference between the two tasks: The cross-dimensional cost and the intertrial effects were present in the detection nonsearch task but were absent in the compound non-search task (see also Theeuwes et al., in press). These data are crucial for the localization of these effects. These findings show that these effects do not occur at the perceptual level but rather at the response selection stage.

One might argue that there was no need to actually process the surrounding stimulus in the compound nonsearch task. Participants had to respond to a line segment presented inside a single object, presented in the center of the visual display. As there was always a line segment present, there was indeed no need to process the surrounding stimulus. Participants could have narrowed their focus of attention only to the line segment, and the stimulus would not be processed. Therefore, one may argue that it is not surprising that there were no dimensional-based effects. Even though this is a viable explanation, it should be realized that some processing of the surrounding stimulus occurred. In the cross-dimensional condition of the compound nonsearch task, there was an effect of type of target stimulus, $F(2, 22) = 6.9$, $p < .01$. Participants were faster to respond to a line segment presented inside a red circle (479 ms), relative to a line segment presented in a gray big circle (488 ms) or in a gray triangle (491 ms). In other words, participants did process the surrounding stimulus. In addition, the actual RT to the line segment inside the red circle (479 ms) observed in the present task is similar to the RT observed in a comparable condition (Theeuwes, 1992, Experiment 1), in which it was certain that participants had to search and process the red circle and respond to the line segment inside. Therefore, it is likely that participants did process the surrounding stimuli.

Note that the results of the detection task were a replication of the results of Experiment 1 (nonsearch task) and Experiment 2. As

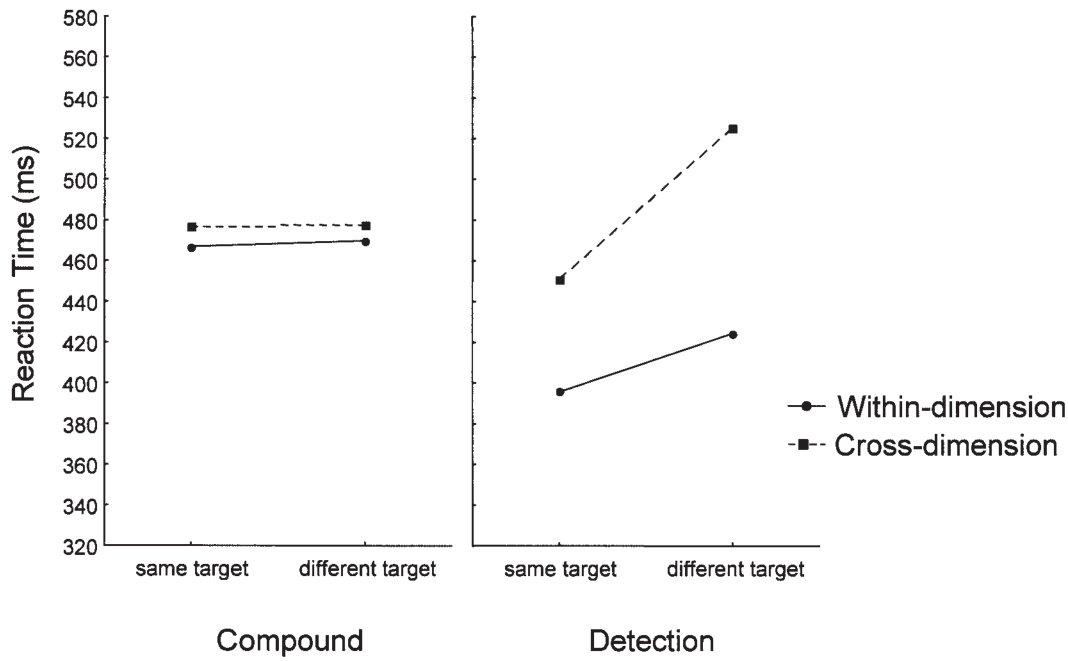

Figure 8. Experiment 5: Mean reaction times and error percentages as a function of task (compound or detection), condition (within dimension or cross-dimension), and intertrial effects (same target or different target on the previous trial).

in Experiment 2, there was an intertrial effect in the within-dimensional condition. However, this effect was absent in the within-dimensional condition of Experiment 1. It is unclear why this difference occurred.

General Discussion

The present study has important implications for several leading visual search theories. Almost all visual search accounts (Müller et al., 2003; Wolfe et al., 2003) assume that top-down knowledge guides attention toward the target singleton. For example, the guided search (Wolfe et al., 2003) account assumes that top-down knowledge improves visual search for a singleton target. It is assumed that target selection is modulated by intentional, knowledge-based processes. Because processing is tuned to a specific dimension (i.e., the cued dimension), it is assumed that visual search for the relevant feature dimension is speeded. This mechanism explains benefits for within-dimensional over cross-dimensional search, dimension-specific intertrial effects, and explains advance dimension-cueing effects. The present study replicates these findings but demonstrates that these effects have nothing to do with actual guidance of search. The present results were obtained in a task in which there was no guidance of search because there was nothing to search for. Furthermore, these effects disappeared when the response requirements were changed. Indeed, in Experiment 5 in both tasks (nonsearch detection and nonsearch compound), exactly the same visual stimuli were presented, but the response requirements were different. Just by changing the response requirement, the reliable cross-dimensional and intertrial effect that occurred in the detection task completely disappeared in the compound task. This experiment demonstrates that effects that typically have been attributed to early top-down visual modulation (e.g., Found & Müller, 1996; Müller et al., 1995; Wolfe et al., 2003) may represent effects that occur much later in processing, possibly related to response selection.

Experiments 1 and 2 investigated whether the cross-dimensional cost and intertrial effects, typically attributed to search processes (e.g., Wolfe et al., 2003), would persist in a nonsearch task. The results showed a significant increase in RTs of 42 ms in Experiment 1 and 59 ms in Experiment 2 when the dimension defining the target was not known in advance relative to when the target-defining dimension was known. Both experiments showed a significant facilitation of target repetition, as is found in previous studies (e.g., Hillstrom, 2000).

Experiments 3 and 4 were designed to test whether cueing effects regarding the identity of the target (the dimension or the feature value) found in a feature search task (e.g., Müller et al., 2003) could also be found in a nonsearch task. Experiment 3 showed that cueing the dimension of a target resulted in faster detection of the target relative to invalid cueing. Experiment 4 revealed also a dimensional validity effect, with a feature-specific cueing effect. The intertrial effects in Experiment 3 showed a feature-specific intertrial effect as well as a dimensional intertrial effect, but only for color targets. The intertrial effects in Experiment 4 revealed only a dimension-specific intertrial effect. Thus, there was a feature-specific intertrial effect present when the target was cued by a verbal feature value but absent when the target was cued by a verbal dimensional value. It could be that a feature cue sums up with the feature-specific intertrial effects, resulting in significant intertrial effects, whereas a dimensional cue can only influence dimensional intertrial effects and no feature-specific values.

Experiment 5 was designed to determine whether the effects occur on a perceptual level or more on a response selection stage. The results showed a clear distinction between the detection task and the compound nonsearch task. In the detection task, the cross-dimensional cost and the intertrial effects were present, whereas in the compound task, these effects were absent. These findings suggest an interpretation in terms of a response-based account. Our findings are in line with data presented by Wolfe et al. (2003, Experiment 6). Similar to our set up, Wolfe et al. used a detection or compound nonsearch task. They reported clear cross-dimensional costs in the detection nonsearch task (of about 114 ms) but hardly any costs in the compound nonsearch task (of about 12 ms). These findings are the same as we report here. Note that if the cross-dimensional cost is attributed to the deployment of attention, then this cost should be around zero in the detection nonsearch task because there is nothing to search for.

Even though Wolfe et al. (2003) and the present study found no cross-dimensional costs and intertrial effects in a compound nonsearch task, the literature is less clear-cut regarding cross-dimensional costs and intertrial effects in a compound search task. On the one hand, Kumada (2001, Experiments 1a and 1b) showed cross-dimensional costs and intertrial facilitation effects in a detection search task but not in a compound search task. In line with these results, Theeuwes et al. (in press) found dimensional-cueing effects in a detection search task but not in a compound search task. In contrast to Kumada (2001), Krummenacher et al. (2002) found a cross-dimensional cost and dimension-specific intertrial effects in a compound search task in which participants had to discriminate between left- or right-pointing stimuli. Also Wolfe et al. (2003, Experiment 5) found a cross-dimensional cost and a dimensional intertrial effect in a compound search task. At this point, it is not clear why some find cross-dimensional costs and dimension-specific intertrial effects in a compound search task, whereas others do not. The bottom line, however, is that in a nonsearch task, as we used here (see Experiment 5), the compound task did not result in cross-dimensional costs and intertrial effects, a finding that is similar to that reported by Wolfe et al. (2003, Experiment 6).

The present obtained results are in line with the dimensional action account, suggested by Cohen and colleagues (Cohen & Feintuch, 2002; Cohen & Magen, 1999; Cohen & Shoup, 1997). In a within-dimensional condition, the participants know the dimension in which the target will appear. According to their model, this knowledge primes the relevant dimension-specific response selection mechanism. In contrast, in the cross-dimensional condition, there are more response selection mechanisms necessary to perform the task. As a result, the priming in the within-dimensional condition gives an advantage relative to the cross-dimensional condition. With this model, the cross-dimensional cost in Experiments 1 and 2 could be explained. This view could also be applied to the cueing effects found in Experiments 3 and 4. A valid cue in Experiment 3 indicates the dimension of the upcoming target. In that case, the dimension-specific response selection mechanism will be primed or will receive larger weight relative to an invalid cue, which primes a different (the wrong) selection mechanism. In Experiment 4, the valid cue indicates the target feature value. According to the response-based account, a feature cue primes the dimension-specific response selection mechanism. Indeed, dimensional-cueing effects were obtained.

Note, however, that in the present feature-cueing experiment, there were also feature-specific cueing effects. This can also be explained by Cohen's dimensional action account (Cohen & Feintuch, 2002; Cohen & Magen, 1999; Cohen & Shoup, 1997). The feature-specific cueing effects could be attributed to decision processes after the target has been selected (see also Theeuwes, 1992, 1994). It seems that these feature cues assign a larger weight to a specific feature-to-response mapping. As noted in Cohen and Shoup (1997), "the response selection system can have direct access to the feature maps within each dimension" (p. 174).

Furthermore, the intertrial effects in the present study are also in line with a dimensional action account. The dimension-specific intertrial effects of Experiments 3 and 4 can be explained in a similar vein as the cueing effects. A certain trial is responded to faster if the same response mapping for target dimension is repeated relative to when it is not repeated. This mechanism can also be applied to the feature-specific intertrial effects in Experiments 1, 2, 3, and 5. It could also be that intertrial effects are a result of perceptual priming (see also Olivers & Humphreys, 2003). However, if this were indeed the case, we would have also found feature-specific intertrial effects for the shape targets in Experiment 3, for both target dimensions in Experiment 4, and also in the compound task in Experiment 5.

It is plausible to assume that cross-dimensional costs and intertrial effects have a locus in more decisional or response selection processes. The results of Experiment 5 are totally in agreement with the dimensional action model of Cohen and colleagues (Cohen & Feintuch, 2002; Cohen & Magen, 1999; Cohen & Shoup, 1997). The stimulus-to-response mapping in the compound task is between the horizontal line (inside the target) and a keypress or between the vertical line and another keypress. In other words, there is only one response selection mechanism necessary to perform the task. This is the case as well for the within-dimensional condition and the cross-dimensional condition. This explains why there are no differences between these two conditions. As previously noted, there are contradictory findings concerning the presence or absence of these effects in compound tasks.

In line with the dimensional action model proposed by Cohen and colleagues, we adhere to the position that perceptual analysis may proceed in parallel across the visual field. However, in order to select a response, focal attention must be shifted to the location of the target. The crucial question addressed here is whether cross-dimensional and intertrial effects operate on processes that occur before attention is shifted to the location in space (i.e., involved in guidance of attention to the location of the target; cf. Wolfe et al., 2003) or occur after attention is focused on the location of the target. Obviously, because the present article shows that without search, similar effects can be obtained, we believe that cross-dimensional and intertrial effects operate on processes that occur after attention has been shifted to the location of the target.

It is clear that the present findings can be explained by a response-based account. However, previous research has also shown a cross-dimensional cost in a nonsearch task and explained this finding by the dimensional-weighting theory (Müller & O'Grady, 2000). Even though Müller and O'Grady (2000) also used a single stimulus in the center of the display, the paradigm was very different. In Experiment 2 of their study, participants had to judge two attributes of a single object, either belonging to the same dimension, for example, the dimension form (line size and texture), or belonging to two different dimensions, for example, form (texture) and color (hue). The stimulus displays were presented briefly and then masked. Response accuracy was measured, and there was no time pressure. Judgment accuracy was reduced for the condition in which participants had to judge two attributes, each in one dimension, relative to the condition in which these two attributes were in one dimension. Müller and O'Grady (2000) interpreted this cross-dimensional cost as evidence for "a limit to the attentional weight that can be allocated at any one time to the various dimensions on which an object is defined" (p. 1349). This is in line with the dimensional-weighting account, which states that the attentional weights allocated to the visual dimensional modules are limited. As suggested by Müller and O'Grady (2000), the effect most likely has it origin in perceptual processes rather than in response-related processes because the stimulus displays were presented briefly and then masked. Because participants had ample time to respond, the argument is that the effect cannot be response related. It seems that this result is in contrast to a response-related account for dimension-based effects. However, there are two important differences between the cross-dimensional cost found in the study of Müller and O'Grady (2000) and the cross-dimensional cost that occurred in the search and nonsearch tasks, as presented in this study. First, the cross-dimensional cost in Müller and O'Grady's (2000) study is different from the typical cross-dimensional cost found in classic visual tasks (e.g., Müller et al., 1995; Treisman, 1988) and costs found in the present nonsearch task. In Müller and O'Grady's (2000) study, an object needed to be selected, followed by a judgment of the two object attributes in two different dimensions. A switch from one dimension to the other for each trial is necessary to give the two correct responses. In contrast, the typical cross-dimensional cost comes from switches on a trial-by-trial basis. That is, in a cross-dimensional condition, participants have to respond to a target in one dimension in one trial, whereas on the next trial, they may have to respond to a target in another dimension. Second, and relatedly, in the cross-dimensional condition in Müller and O'Grady's study, participants knew in advance the two dimensions they were required to judge. In contrast, in the cross-dimensional condition of the present study, participants did not know prior to target presentation the dimension in which the target would occur, so they did not know to which dimension they had to respond.

Still, it may be possible to explain the present results in terms of dimensional weighting. As was suggested in Müller and O'Grady (2000), even in a nonsearch task, participants still have to segregate the stimulus from the empty background, and a saliency signal needs to be computed, just as in a visual search task. In the framework of dimensional weighting, this computation is dimension specific. For example, on the one hand, in a within-dimensional condition, the target-defining dimension is known in advance so that dimension is assigned a larger weight than the other dimensions. On the other hand, in a cross-dimensional condition, the dimension of the target is not known in advance, and thus no specific dimension receives a larger weight. This interpretation is possible; yet, it is hard to maintain such a position when the effect size for search with distractors is basically the same as nonsearch without distractors (see Experiment 1). Indeed, one would expect that the role of a saliency signal is much larger when distractors are present than when they are absent.

It is important to note that some recent functional magnetic resonance imaging studies also provided evidence for the dimensional-weighting account (Pollmann, Weidner, Müller, & von Cramon, 2000; Weidner, Pollmann, Müller, & von Cramon, 2002). A distinct network of brain structures was raised tonically during epochs, starting from a switch to that dimension until a switch to the alternative dimension in cross-dimensional conjunction search. This supports the assumption that there exists visual dimension-specific modules in which stimuli are analyzed into basic features, which is commonly assumed. Furthermore, this was interpreted as a dimension-specific "memory" that biases the system toward detecting signals in the respective dimension. However, with respect to the present debate (whether the effects are perceptual or response based), it is not clear whether these activations represent processes associated with perceptual or response selection analysis. It is clear that dimension-specific modules exist; however, it is unlikely that functional magnetic resonance imaging data can resolve the dispute about whether these effects are perceptual or response related in nature. Even though the dimensional-weighting account provides some explanation for most of the present results, it should be noted that it does not provide much explanation for the findings of our Experiment 5. Müller and colleagues (Müller et al., 1995, 2003) would predict the same cross-dimensional cost and the intertrial effects in a compound task relative to a detection task because these effects are assumed to be perceptual. If the visual stimulation remains the same, but the response demands are different, then no difference in perceptual processing is needed. However, the results showed a difference in response selection or response mapping mechanisms in the compound task relative to the detection task. To account for these results by a perceptual account, one has to assume that the perceptual stimulus analysis is different in both tasks because both tasks require a different analysis of the stimulus in order to give the correct response. Müller et al. (2003) suggested that detection responses can be triggered directly on the detection of activity in the overall saliency map without requiring focal attentional analysis. In this sense, a response-related role is ascribed to the activity of the saliency map units (see Müller et al., 2003, p. 1033). This means that the response selection mechanisms are also dimensionally weighted. This line of reasoning makes it difficult to differentiate between this account and the response-based account.

In summary, the present study showed that specific effects, typically attributed to top-down guidance-of-search processes, also occur in conditions in which there is no search. Moreover, these effects disappear when the response requirements are changed but the visual stimulation remains the same. Therefore, we conclude that these effects are the result of later processes, presumably response selection.

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